POSSIBILITIES OF USING NUCLEAR ENERGY FOR GASIFYING COAL

By James P. McGee and Sidney Katell

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POSSIBILITIES OF USING NUCLEAR ENERGY FOR GASIFYING COAL[1]

by

James P. McGee[2] and Sidney Katell[3]

SUMMARY

Preliminary calculations show an economic advantage in using nuclear energy to supply the endothermic heat required for gasifying coal. It should be noted that the various assumptions used in preparing these calculations must undergo further evaluation through additional engineering design and research.

The proposed system for gasification is the indirect process cycle with helium heated in a nuclear reactor and passed through an exchanger-type gasifier for the reaction of coal and steam to form CO (carbon monoxide) and H_2 (hydrogen gas).

A conceptual design of a system to produce 14 million std. c.f. per hour of CO + H_2, which could be further processed to produce 90 million std. c.f. per day of high B.t.u. gas, is described. The process involves the gasification of 311,000 pounds per hour of a low-rank coal. The process heat required would come from three 250-thermal megawatt reactors, using slightly enriched uranium as fuel.

To test the feasibility of this system, the Federal Bureau of Mines has constructed a high-temperature helium loop to test components such as heat exchangers, recycle compressors, and valves. Heat is generated by graphite spheres heated in an induction field.

INTRODUCTION

Several processes that have been conceived for producing synthetic pipeline gas from coal were considered in a recent publication by Katell (4)[4].

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[4] Underlined numbers in parenthesis refer to items in the bibliography at the end of this report.

One of these processes involves the use of heat from a nuclear process-heat reactor to gasify coal at elevated temperature and pressure. The application of nuclear energy to coal gasification may have an economic advantage, as illustrated by the following preliminary cost analysis for 90 million std.c.f. per day synthetic pipeline gas plants.

Process	Estimated capital cost	Cost of 1,000 std.c.f. of product gas: Before return on investment	Cost of 1,000 std.c.f. of product gas: After 12 percent return on investment
Entrained oxygen-steam-coal gasification.....	$84,000,000	$0.70	$1.04
Steam-coal gasification (nuclear heat)...	72,000,000	.60	.89

Acting under a cooperative agreement with the Atomic Energy Commission, the Bureau of Mines has begun an investigation dealing with the application of nuclear energy as a source of process heat (5). This program has been directed toward developing an indirect process cycle, with helium heated in a nuclear reactor, then passed through an exchanger-type gasifier for the reaction of coal and steam. Although the design of components for a coal-gasification system is beyond the scope of this manuscript, enough work has been done by the AEC and the Bureau of Mines to allow the design parameters to be fixed.

This article will describe a conceptual design of a system to utilize nuclear heat for coal gasification and will describe apparatus that has been built to simulate the operation of a high-temperature nuclear system.

ACKNOWLEDGMENTS

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PROCESS DESCRIPTION

The gasification section of the process, which was used to establish the economic advantages of application of nuclear heat, is shown schematically in figure 1. Water and coal in the ratio of approximately 1.5 pounds of water to 1 pound of coal (dry ash-free basis) are introduced into a slurry mix-tank. After thorough mixing, the slurry is pumped through preheater tubes, the water flashed into steam, and the coal-steam mixture preheated to 600° F. The coal-steam mixture then enters the gasifier and is superheated and gasified at about 1,700° to 1,800° F.

The heating medium for the preheating and gasification is helium recycled through a nuclear reactor. The pressure of both the recycled helium and proc-

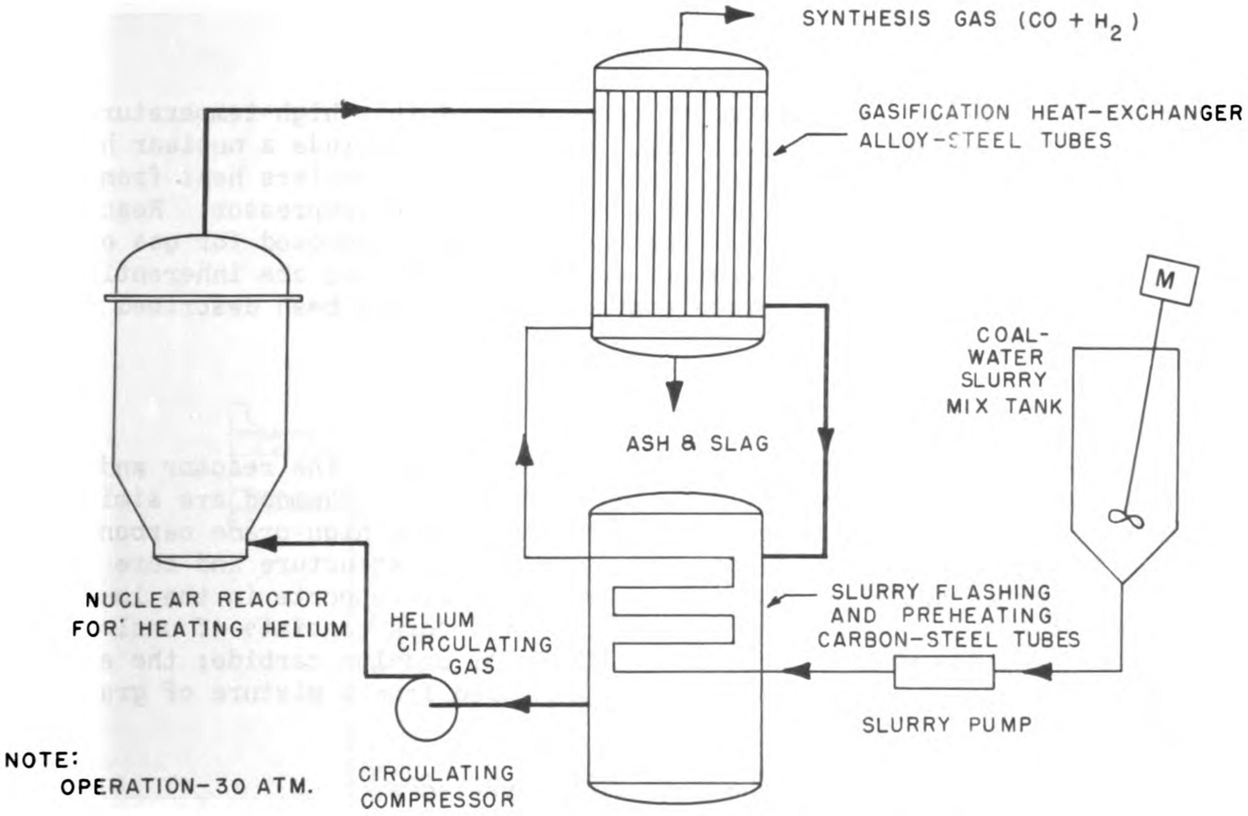

FIGURE 1. - Simplified Flowsheet for Gasification of Coal Using Nuclear Heat.

ess streams is balanced at 30 atmospheres; hence, the stress in the tubes due to pressure is almost eliminated, and the tubes can be used at higher temperatures than otherwise.

A preliminary study of a nuclear heat, coal-gasification process to produce 90 million std.c.f. per day of high-B.t.u. gas shows the following characteristics:

Raw synthesis gas ($CO + H_2$) produced: 14 million std.c.f. per hr.
Coal type: Lignite or sub-bituminous
Coal required: 311,000 pounds per hr. (dry)
Steam required: 467,000 pounds per hr.
Nuclear reactor (3) heat output: Approximately 750 thermal megawatts
Helium recirculation rate: 1,485,000 pounds per hr.
Nuclear reactor outlet temperature: 2,450° F.
Nuclear reactor inlet temperature: 1,060° F.
Helium pressure: 450 p.s.i.g., maximum
Pressure drop: 10 to 40 p.s.i.
Recycle compression ratio: 1.023 to 1.095

Compressor brake horsepower: 11,500 to 46,000 (depending on pressure drop)
Total gasifier tube-surface: 60,000 to 120,000 sq.ft. (depending on pressure drop)

EQUIPMENT

Conceptual designs for the major components of this high-temperature system have been described by Dalzell (1). Major units include a nuclear heat source (reactor); a heat exchanger (gasifier), which transfers heat from the helium to the coal-steam mixture; and a helium recycle compressor. Reactor systems for operation at lower temperatures have been proposed for gas or steam turbine plants. These low-temperature systems, which also are inherently capable of producing high-temperature process heat, have been described by Robinson (6) and Hammond (3).

Nuclear Reactor

This is the heat source for the coal gasification. The reactor and reactor-core designs prepared by Dalzell, Robinson, and Hammond are similar. One such design is shown in figure 2. Fabricated from high-grade carbon-steel plate, the vessel is a right cylinder, with internal structure and core consisting chiefly of graphite and with stainless steel supports in the low-temperature (that is, helium-inlet) section. The core consists of unclad fuel-elements of graphite with either uranium oxide or uranium carbide; the element is either impregnated with uranium or manufactured from a mixture of graphite and uranium.

This type of element has the following advantages:

1. It can be used at high temperatures. (Daniels (2) has proposed a graphite-uranium carbide element which he believes can be operated at 4,000° F.);

2. The elements are unclad; hence, better neutron economy is effected;

3. Unclad elements are less expensive to manufacture and cheaper to reprocess.

Because fission products can escape from unclad elements, the principal disadvantage to this type of element would be radioactivity in the helium stream; however, a portion of the main helium stream can be purified continuously, so this fission-product contamination may not be too critical. Furthermore, some work is being done by several leading manufacturers in the ceramic field on the development of a gastight element.

The reactor core is surrounded by a carbon reflector to retain some of the neutrons that would otherwise escape. Also, since this reflector will be subject to gamma heating, it must be cooled. One way to accomplish this cooling would be to channel some of the relatively cooler inlet-helium through the reflector.

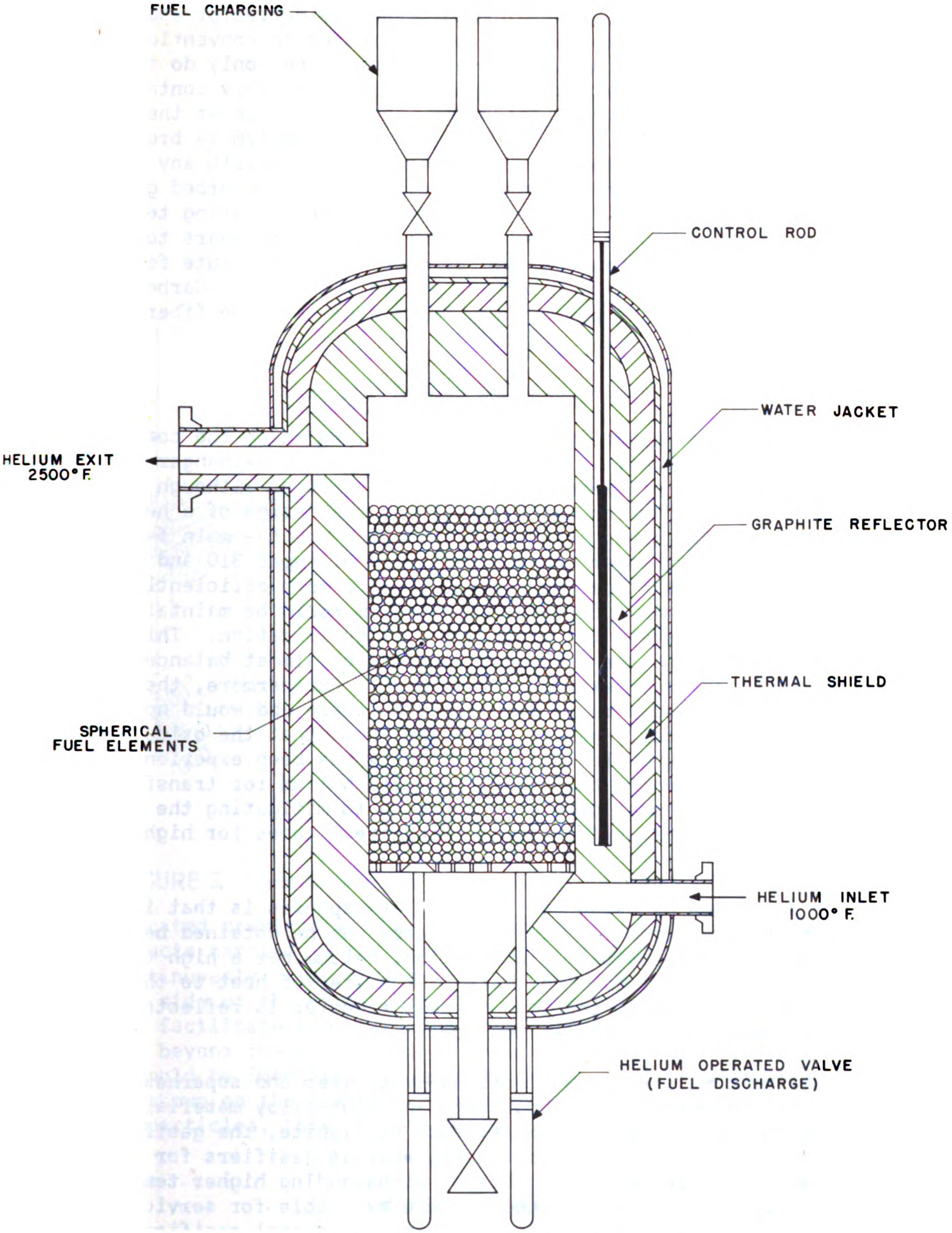

FIGURE 2. - Nuclear Reactor for Coal Gasification.

Thermal insulation must be provided between the reflector and the pressure shell. So far, most attention has been directed to conventional insulation, such as aluminum or magnesium oxide. However, not only do these oxides tend to react with graphite at higher temperatures, but they contain both absorbed water and water of crystallization, and experience at the Morgantown, W. Va., Coal-Research Center has shown that when the system is brought to operating temperature, this water is expelled and reacts with any carbon present. Moreover, these insulating compounds also contain absorbed gases, such as oxygen and hydrogen, that react with carbon in the operating temperature range. Carbon black, which has been used for a number of years to insulate high-temperature electric furnaces, may be used as a substitute for the metal oxides. Carbon black in granular form is a good insulator. Carbon black also can be formed as fibers, and preliminary tests show that the fibers have good insulating qualities.

Heat Exchanger

The heat exchanger (that is, coal gasifier), in which the coal and steam react to form synthesis gas, is shown in figure 3. The exchanger-gasifier presents as many design problems as the nuclear reactor, although some features of the proposed nuclear system are favorable to the design of a heat exchanger-gasifier. For example, creep stress and oxidation are the main factors limiting the life of heat-exchanger tubes constructed of types 310 and 316 alloy steel. Gas-cooled nuclear reactor systems operate more efficiently if the helium coolant-gas is under pressure. The helium would be maintained at 30 atmospheres--a good pressure for efficient coal gasification. This would allow the pressure across the exchanger tubes to be almost balanced and the creep stress confined to an extremely low level. Furthermore, the heat source side of the tube wall would be in a helium atmosphere and would not oxidize. Experience with electrically-heated tubes has shown that the oxidation due to air or oxygen is severe, while little difficulty has been experienced with steam-coal mixtures. Hence, the use of recycled helium for transferring nuclear heat offers the most promising approach to mitigating the disadvantages that inherently limit the usefulness of alloy-steel tubes for high-temperature operation.

Another advantage of using helium at 30 atmospheres is that increased rates of heat transfer from the nuclear reactor can be obtained because of the much larger mass flows possible. In addition, helium has a high thermal conductivity, which also increases the rate of transfer of heat to the steam-coal mixture, and any increase in the rate of heat transfer is reflected in a corresponding decrease in heat-transfer surface.

The gasifier consists of two sections--vaporizer and superheater-gasifier. Carbon steel can be used in the vaporizer, and high-alloy materials in the gasifier section. With low-rank coals, such as lignite, the gasifier tubes can be constructed of type-310 alloy steel, whereas gasifiers for coals of higher rank will require metals capable of withstanding higher temperatures. Materials such as molybdenum and tungsten are available for service above 2,200° F., but their present cost is prohibitive for coal gasification application. Moreover, since such materials are subject to steam attack, the inside of the tubes would have to be protected by chromium or nickel cladding.

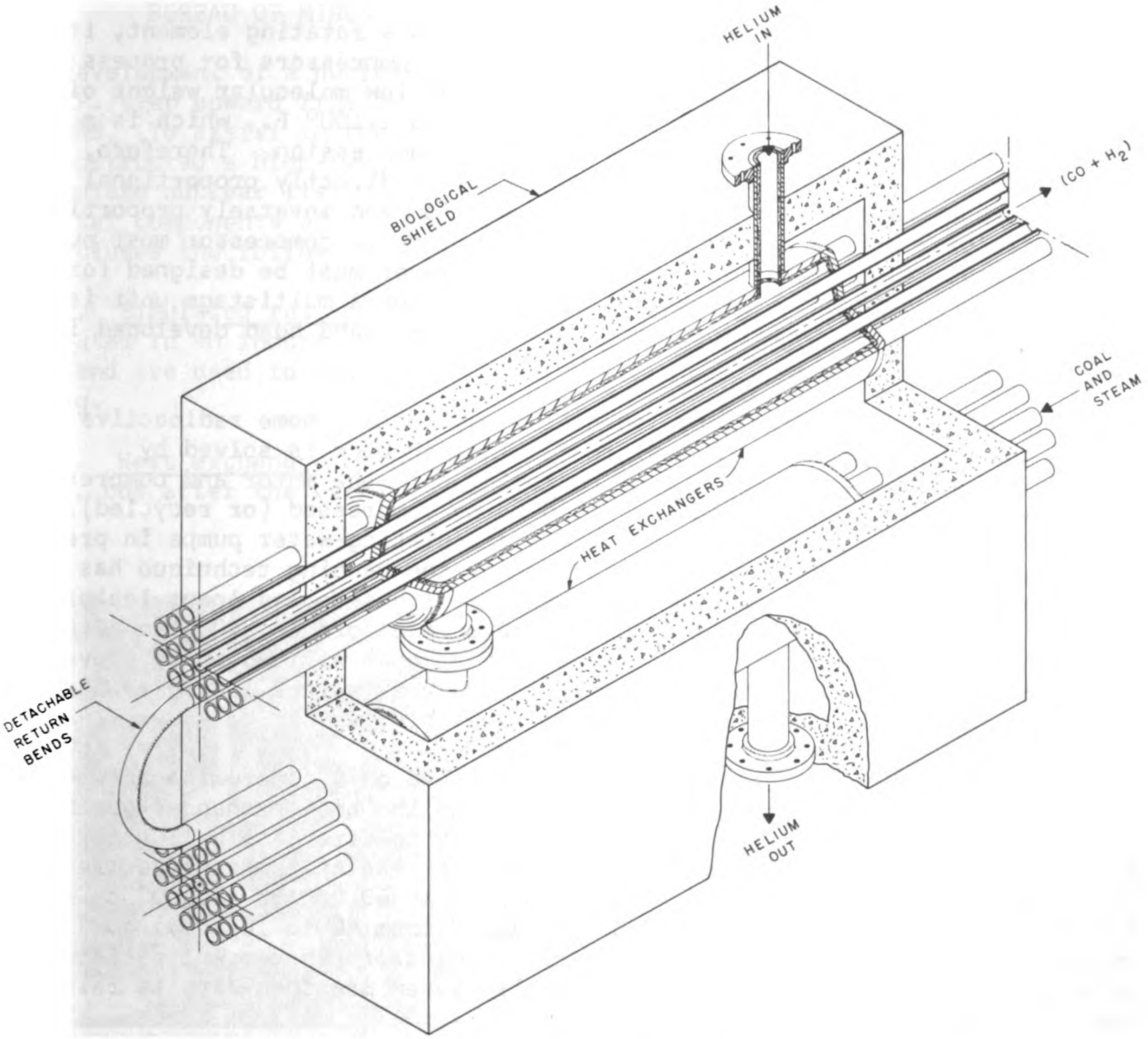

FIGURE 3. - Heat Exchangers for Coal Gasification Using Nuclear Heat.

As indicated previously, the helium coolant would become radioactive from fission products carried in the gas stream. Although this stream would be purified continuously, some of the fission products undoubtedly would deposit on the shell side of the exchanger, so the exchanger must be shielded. Furthermore, to facilitate tube-cleaning, the tubes containing the slurry mixture must project beyond the biological shield. The tube turns outside the pressure shell would be insulated and encased in a jacket of stagnant, pressurized helium (not shown on the sketch). Since this helium would not contain any radioactive particles, this jacket can be depressurized and removed for cleaning.

Recycle Compressor

As the recycle compressor, which circulates the heat-conveying helium through the nuclear reactor and the heat exchanger-gasifier, is the only piece of equipment in the high-temperature loop that has a rotating element, it is the major power-consumer in the system. Recycle compressors for process heat reactors will require a special design due to the low molecular weight of helium and the high inlet temperature of 1,000° to 1,100° F., which is much higher than in conventional processes requiring compression. Therefore, since the head against which the compressor must pump is directly proportional to the absolute temperature of the gas at the suction and inversely proportional to the molecular weight of the gas, the helium recycle compressor must pump against a high head. This means that the compressor must be designed for high tip-speeds to provide high peripheral velocities, or a multistage unit is required. (The relation between peripheral velocity and head developed is approximately $V^2 = 2\ gh$.)

In addition, since the recycled helium may contain some radioactive particles, the compressor must be leakproof. This problem is solved by "canning"--a technique consisting of enclosing both the motor and compressor in a pressure vessel containing the fluid being compressed (or recycled). This technique has proven satisfactory for circulating-water pumps in pressurized-water reactor systems. Application of the canning technique has been the first approach to the problem of making small gas-cooled loops leakproof. Commercial-size reactor systems with recycle compressors of 2,000 to 10,000 hp. may require the development of a compressor seal that will entirely prevent helium leakage, or, at the worst, permit only a very slight leakage. Canning of compressors of this capacity may not be feasible.

The overall design of the compressor is based on a compromise between heat-transfer surface in the nuclear reactor and the heat exchanger-gasifier, and the power required by the recycle compressor to circulate helium through the system. Preliminary calculations reveal that the heating surface required in the heat exchanger increases from approximately 60,000 to 110,000 sq.ft. when the pressure drop in the system is reduced from 40 to 10 p.s.i.g. The calculated brake horsepower of the recycle compressor (85 percent efficient) increases from 11,500 to 46,000 hp. when the system pressure-drop is raised from 10 to 40 p.s.i.g.

ASH AND RESIDUE REMOVAL

From the gasifier the product gas containing ash and unreacted carbon would first pass through a waste-heat boiler, then through a conventional purification system. Because of the low temperature level of gasification, slagging of the ash should present no problem. There would be no induced radioactivity in the solid residue. A waste heat boiler would be provided after the gasifier, since additional steam is required in the overall plant balance.

A hot dust purification train followed by shift with a sulfur resistant catalyst is under study. This would allow the unreacted steam to be utilized in the shift converter. If the hot dust system proves to be inoperable, cyclones followed by water scrubbing will be used.

BUREAU OF MINES PROCESS HEAT REACTOR DEVELOPMENT PROGRAM

Development of a nuclear reactor to heat helium to 2,500° F. represents a 1,000°F. step upward from any of the gas-cooled power reactors now being designed. To assist in the development of such a reactor, the Bureau of Mines has constructed a high-temperature system using electrical induction heating to simulate nuclear fission. This loop, shown in figure 4, consists of the essential components of the process heat reactor system previously described and includes the following units:

1. Simulated reactor. - This is a pressure vessel in which carbon spheres are heated in an induction field. These spheres simulate nuclear fuel elements and are used to heat recycled helium to 2,500° F. at a pressure of 250 p.s.i.g.

2. Heat exchanger. - In this exchanger, heat is transferred from helium to air, but after the various operating problems inherent in the helium recycle

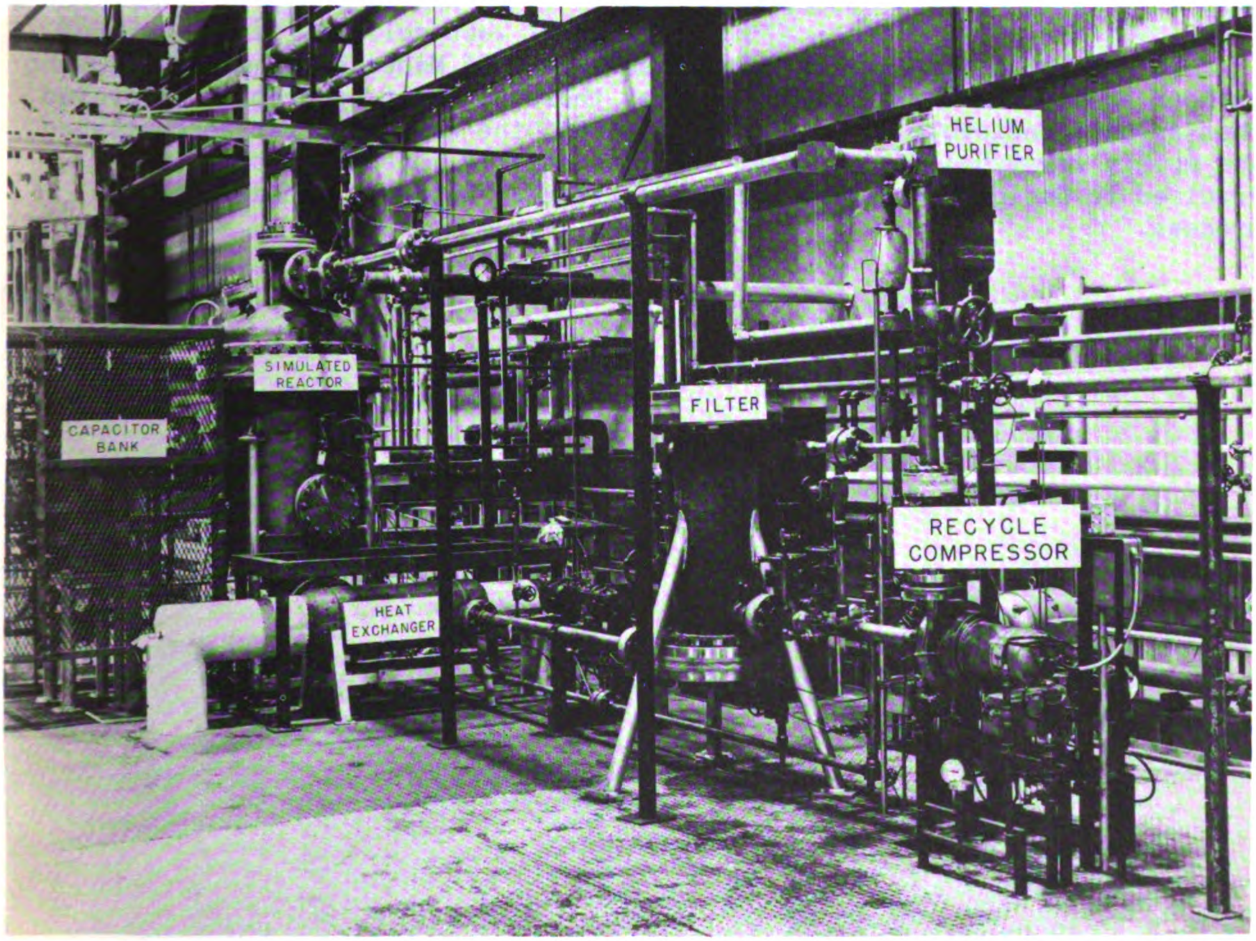

FIGURE 4. - 2,500° F., 250 p.s.i.g. Helium Recycle Loop.

circuit are solved, this helium-to-air exchanger will be replaced by a coal gasifier.

3. Recycle compressor. - This machine circulates the helium through the simulated-nuclear reactor and the heat exchanger. It is a single-stage centrifugal type, with an 8.5-inch impeller powered by a 400-cycle induction motor. The pressure rise is 5 p.s.i. with a static pressure in the system of 250 p.s.i.g., which corresponds to a head of 11,000 feet at a helium-inlet temperature of 1,000° F. The entire assembly is hermetically sealed or canned.

CONCLUSIONS

The application of nuclear energy to supply the reaction heat for a low-rank coal will entail a long-range development program. This development will center principally on the nuclear reactor to heat the helium to the high temperatures required and an exchanger to transfer this heat for the gasification of coal.

Use of existing alloys should allow the construction of a gasifier suitable for lignite or sub-bituminous coal.

In a joint Atomic Energy Commission-Bureau of Mines program for applying nuclear energy for chemical process heat there has been no problem uncovered that appears incapable of solution. However, the work thus far accomplished has merely scratched the surface, and considerably more research will be required to design, fabricate, and test all the "hardware" needed for the process.

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